# Ados $CO_2$ Recorder

J. L. Ehretsman

1907

# INSTALLATION AND TEST OF ADOS $CO_2$ RECORDER

# A THESIS

PRESENTED BY

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MECHANICAL ENGINEERING

# I N D E X

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## Purpose of the Apparatus.

Steam users long have appreciated the fact that, in order to obtain the best economy and efficiency, it is necessary to have complete and scientific control of the boiler furnace. With this end in view, various improved types of furnace, mechanical stokers, Dutch ovens and the like, have been invented and put into practical operation.

With the best of these appliances under the care of skilled and watchful firemen there is no doubt that the coal may be handled and burned more economically than with the average fireman; still, losses occur due to a lack of knowledge, on the part of the firemen, of the actual conditions of combustion in the furnace at all times. To remedy this it has been customary for engineers to run occasional evaporative tests on the boilers, and to analyze the flue gas at frequent intervals. To be sure, the average conditions of the working of the furnace may be obtained in this way, but this is not enough. A knowledge of the working of the furnace at all times and continuous control of the same is essential. This is made possible by means of a continuous analysis of the flue gases and by determining the percentage of $CO_2$ they contain.

The burning of the coal which produces the flue gas takes place in two distinct stages: first, the decomposition of the coal and the formation of hydrogen, marsh gas, carbonic oxide, olefiant gas, benzine and other hydrocarbons of the type of marsh gas and benzine, ammonia and sulphur compounds, and coke; second, the combustion or oxidation of these substances. Practically, complete combustion is not obtained and the products form a complex mixture of hydrogen, hydrocarbons, carbon monoxide, water vapor, finely divided carbon, carbon dioxide ($CO_2$), and nitrogen. The last two

mentioned form by far the greater portion of the escaping flue gases, the first mentioned being a very small per cent of the total volume.

The important thing to be considered is the percentage of carbon dioxide formed, since this is produced by a chemical combination of the carbon in the coal with the atmospheric oxygen admitted to the furnace. To effect complete combustion of a known quantity of fuel of a given quality, a certain amount of air is required and no more or less should be admitted to the furnace. Since the percentage of $CO_2$ in the flue gas is dependent upon the quantity of air admitted, it is this percentage of $CO_2$ which discloses whether or not the exact amount of air required is being admitted.

Air contains 21% of oxygen by volume, the remainder being practically all nitrogen. If this oxygen combine with carbon in the furnace, then 21% by volume of carbon dioxide would be the maximum obtainable.

In practice it is found necessary to admit 33% excess air or about 1.3 times that required theoretically. The majority of well equipped furnaces never reach 50% of the maximum, but show 7 or 8% of $CO_2$ in the flue gas which is from 33% to 38% of the theoretically required quantity. The loss in fuel for different percentages of $CO_2$ is shown by the following table:

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage of $CO_2$ obtained | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Corresponding loss in fuel % | 90 | 60 | 45 | 36 | 30 | 26 | 23 | 20 | 18 | 16 | 15 | 14 | 13 | 12 |

To enable the operator of a furnace properly to control the supply of air, it is necessary for him to know at all times just what percentage of $CO_2$ exists in the flue gases. This information

is furnished by the Ados Automatic $CO_2$ Recorder which is designed to analyze the flue gas for $CO_2$ automatically and continuously, and to provide a record of the results for a period of twenty-four hours.

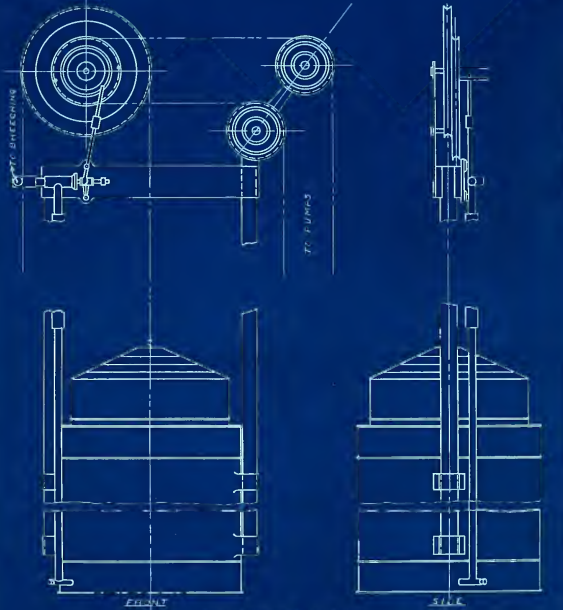
Description of the Recorder and its Operation.

The Ados apparatus consists essentially of three parts: the motor; the gas pumps; the analyzing and recording cabinet. The motor furnishes power to the gas pumps enabling them to draw in a charge of flue gas and drive it into and out of the recording cabinet.

Sketch one attached shows the construction of the motor. The space between the tank and its inner jacket is filled with water. A bell dips into this seal and is counterbalanced by a weight which is attached to it by a wire passing over the large pulley.

A tube enters the tank at the bottom rising to a point above the level of the water in the jacket. This tube is connected to the flue at a convenient point and the draft, which need be only one-half inch of water, exhausts the air from under the bell causing it to move downward into the tank.

This motion continues until the bell reaches the bottom of the tank, when a valve is opened by a stud which throws over a small lever. Air is thus again admitted under the bell through the tube and it is caused to rise by the counterweight. When it reaches the top, the other stud has moved round to the valve lever, which in turn is thrown over. The valve is again closed and the downward movement, actuated by the draft, recommences. Thus a continuous motion is produced by a draft in the chimney of one-half inch of water.



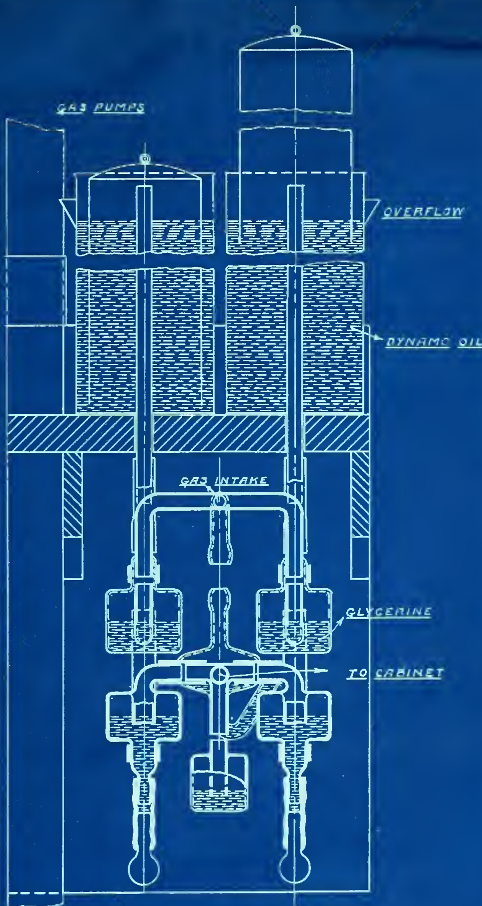

ELEVATIONS OF MOTOR

The gas pumps and valves are shown by sketch two. The pumps comprise two cylinders which dip into oil tanks, rising and falling alternately, drawing flue gases from the chimney and forcing them through the recording apparatus. The cylinders or plungers are constructed on the same principle as the motor, the bells dipping into an oil seal contained in the outer jacket of the tanks; the suction tubes in this case going down through the center.

To the central tubes of the pumps are attached two sets of valves which are so constructed as to prevent the return of any gases which have entered by overcoming the small resistance offered by the glycerine with which they are partly filled. To the lower outlet of the pump valves is attached a sealed escape through which the surplus flue gases, not required for analysis, pass out into the atmosphere.

The operation of the analyzing and recording apparatus, referring to sketch three is as follows: A vessel F, filled with glycerine and water and attached to the counterweight of the motor, rises and falls periodically. When the vessel is at its lowest or normal point, the glycerine extends to the level $m_1$. When the vessel is raised to the highest point of its stroke, the level of the liquid is raised to $m_2$, and the cubic contents of the tube between 0 on the scale and $m_2$ is 100 cubic centimeters.

Incoming gases enter the apparatus through the tube $St_3$ and, the glycerine bottle F, being raised, the level of the glycerine rises from $m_1$ and seals the lower part of the vessel G into which the gases have passed. The glycerine continues rising until it touches the mark 0, when 100 cubic centimeters of flue gas are bottled up, and their exit through the tube $St_4$, through which

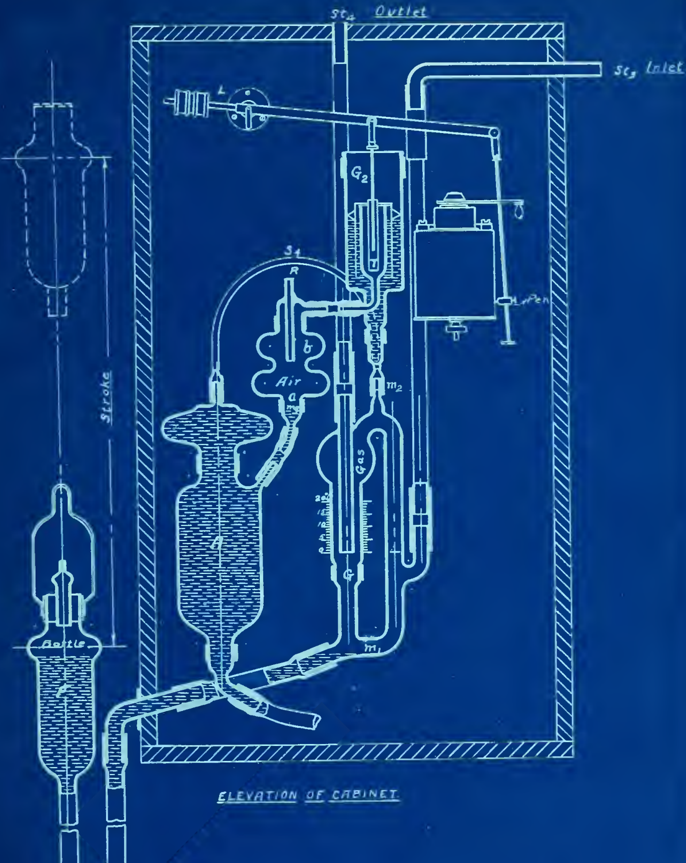


ELEVATION OF PUMPS.

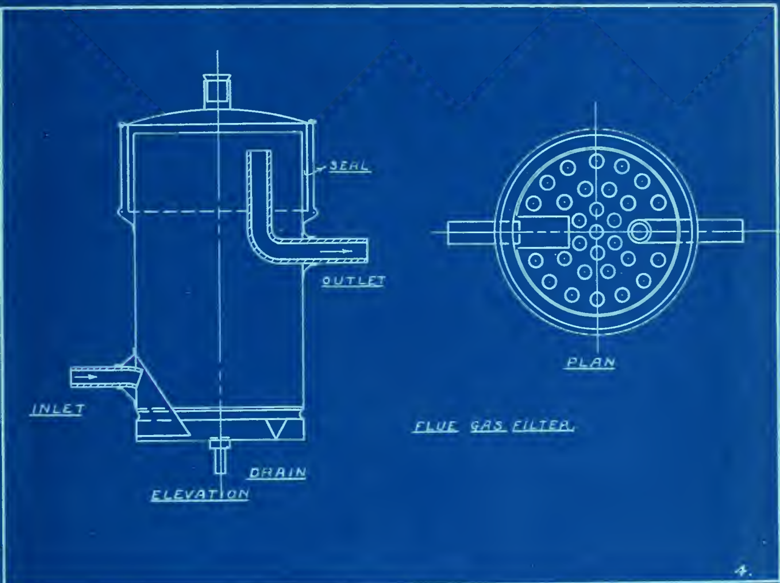
they finally escape, is cut off. The glycerine still rising, enters the gas vessel G, and the gas within that receptacle is thus forced through the tube $S_4$, into the bottle A, which is filled with caustic potash solution, and this absorbs the $CO_2$ present in the 100 cubic centimeters of flue gas. The volume of gas which is not absorbed, replaces an equal volume of caustic solution, and this is forced up into the globe a, and seals the tube R. It can then rise only in the chamber b, and in so doing it presses the air present in this globe into the bell T, which rises and thus lifts the lever L, with which the recording pen is connected. Therefore, the less carbonic acid gas absorbed by the caustic solution in bottle A, the higher the bell T, and consequently the recording pen, will rise.

As soon as F reaches the length of its stroke and begins to return, the level of the glycerine recedes toward $m_1$, its normal point. The flue gases in vessel A return into vessel G and as soon as the mouth of the tube $St_4$ is open once more, by the return of the glycerine beyond that point, are ejected through $St_4$ by the action of the pumps. Owing to the fact that the pumps deliver about twenty times the volume of gases required, the apparatus is exhausted of all traces of a preceding charge and the same gas is never analyzed over again.

The record chart is calibrated in per cents from one to twenty, and time is recorded on it. For every per cent of $CO_2$ absorbed, one cubic centimeter of air less is displaced, and the registering lever rises one per cent on the chart. Consequently, when there is no carbonic acid gas present, the pen rises to the top of the chart. The top of the chart strokes recorded upon the




ELEVATION OF CABINET.




4.

diagram constitutes the $CO_2$ curve.

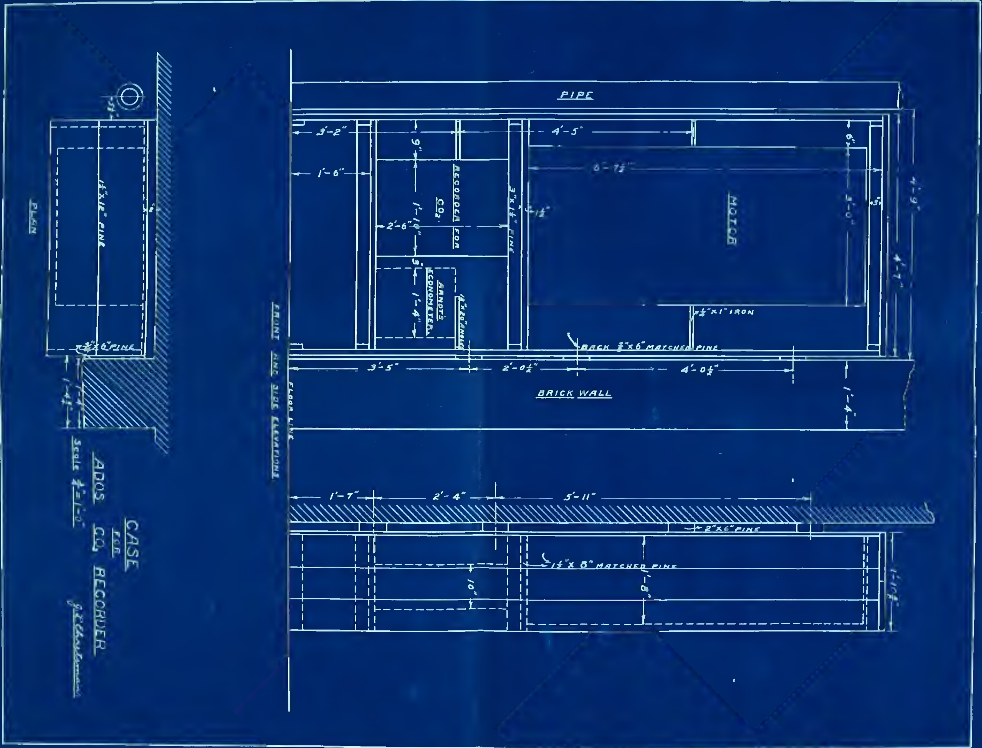
To change the speed of the motor from fast to slow, it is only necessary to reduce the draft or rather the volume of air drawn out from under the bell of the motor. To stop the apparatus, the stopper is removed from the lower tube of the motor or the valve controlling the draft is closed.

Installation.

Referring to the plan and elevation of the installation, it is evident that the most convenient place to install the $CO_2$ Recorder near the boilers was in the angle of the wall south of the stack. It was necessary first to clear the way by tearing out the old piping and siphon which had been used for Arndt's Econometer.

A case was then designed, (see sketch of case), to contain both the Ados $CO_2$ Recorder and Arndt's Econometer, and at the same time to fit into the space available between the obstructions as shown. It was necessary to place the motor above the recording cabinet because of the limited width of the case. The heavy construction of the case is due to the fact that the motor, when the tank is filled with water, weighs two to three hundred pounds.

In order to fasten the case to the wall, one-inch holes were drilled into the west wall of the pump room and into the brick pier. Into these holes wooden plugs were driven to provide a socket for the lag screws used for fastening the three two-by-six-inch strips in the former case, and the three three-quarters-by-five-inch strips in the latter case. The seven-eighths-by-six-inch, matched pine used for the back of the case was nailed to the strips attached to the west wall, while the one-and-one-half-by-



PIPE
3'-2"
4'-5"
9"
1'-6"
6'-7½"
6"
RECORDER FOR $CO_2$
MOTOR
3"x1¼" PINE
1'-10"
2'-6"
3'-0"
4'-9"
4'-7"
ARNDT'S ECONOMETER
1'-4"
1½"x1" IRON
BACK ⅞"x6" MATCHED PINE
3'-5"
2'-0½"
4'-0½"
BRICK WALL
1'-4"
FLOOR LINE
FRONT AND SIDE ELEVATIONS
1'-7"
2'-4"
5'-11"
2"x6" PINE
1¼" x 8" MATCHED PINE
10"
1'-8"
1'-11⅞"

eight-inch, matched pine boards used for the side were fastened to the strips on the pier. Two lower shelves and the other side were constructed of the same material while for the top, one-and-one-half-by-twelve-inch, matched pine was used. This top was merely nailed down. At the top and bottom and under each of the two shelves, cleats were screwed to the sides and back to prevent spreading of the boards. The shelf boards were nailed to the cleats. Four twelve-by-twenty-inch angle irons of one-quarter-by-one-inch, wrought iron were screwed into the corners, two on each side to hold the sides and back in their proper relations and to give stiffness to the case.

It was desired to use the one $CO_2$ apparatus for all the boilers alternately; therefore four pipes carrying the flue gas from the hand-fired boilers were led into a manifold. From the two lower and the two upper deck boilers, three-quarter inch pipes were put up leading through the small doorway as shown by the sketch of the installation, down beside the case into a three-eighths inch manifold. About one foot above the manifold the three-quarter inch pipe was reduced to one-half inch, Lower down it was reduced to three-eighths inch and a cock was placed in each line just above the manifold.

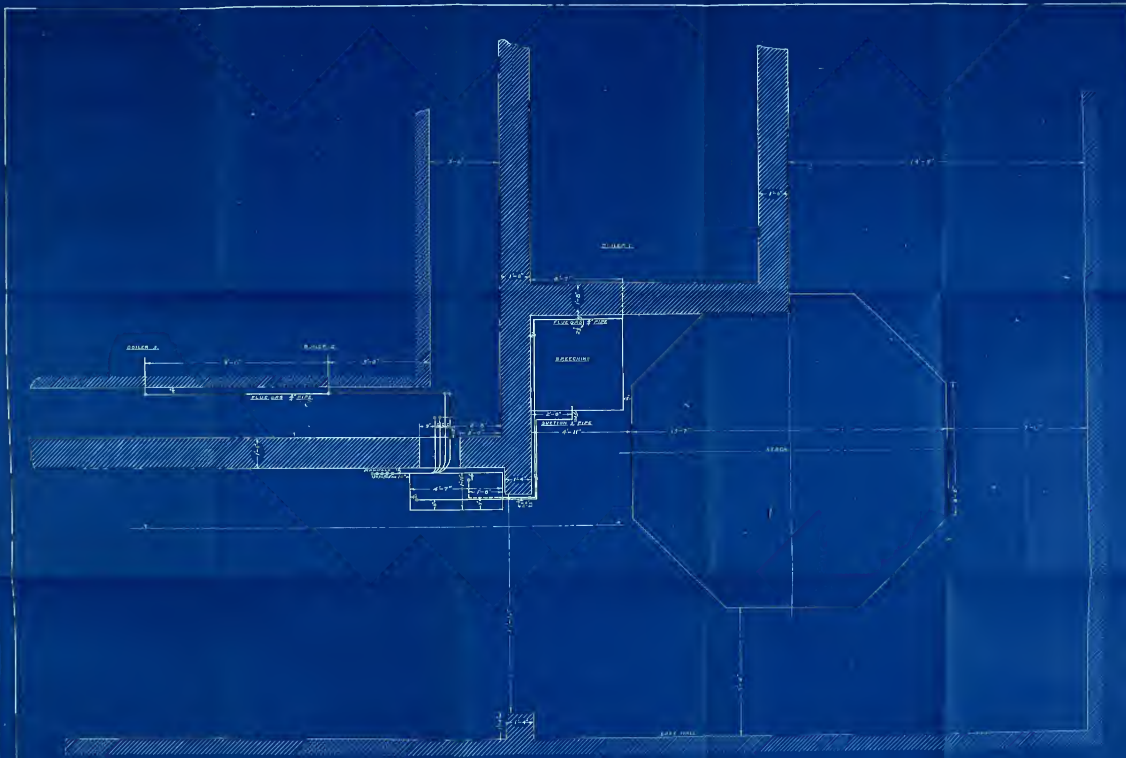
Elbows were used at all right-angle bends except the one just outside the small doorway. Parallel to the boiler leads a three-eighths inch compressed air line was brought down through a cock into the manifold and, by proper manipulation of the cocks above the manifold, compressed air can be blown through any boiler line. From the manifold a three-eighths inch pipe was led through a valve into a three-quarter inch tee from which the

STALLATION

ECORDER

J. L. Ehretsman.

, 1907.




PLAN OF INSTALLATION
ADOS CO₂ RECORDER
M.I.T.
Scale
June 1, 1927


SECTION AT A  SEE PLAN

ELEVATION OF INSTALLATION
ADOS $CO_2$ RECORDER
A.I.T.

Scale ¼" = 1'-0"

June 1, 1907.

pumps take gas.

The flue gas from the mechanically-fired boiler, number one, which was tested, was led by a separate three-quarter inch pipe from the nipple into the above-mentioned tee from which the pumps take gas. A valve was placed in the line to control the flow of gas. All right-angle bends were made by means of elbows. In tapping the boiler a long, perforated nipple was inserted into the rear wall of the boiler and packed at the outer end to prevent infiltration of air around the pipe.

The draft necessary to run the motor was obtained by inserting a short, straight, three-quarter inch nipple into the breeching leading from boilers two and three to the stack. From this nipple a one-inch pipe, containing a valve, was led to the top of the case where it was bushed down, and a three-quarter inch nipple was passed down through a hole in the top of the case. This nipple was tapped at the side and a one-quarter inch pipe was screwed in. From this a short piece of pipe of the same size was brought down parallel to the three-quarter inch nipple. To the latter, the tubing leading to the valve was attached, while to the former, a rubber tube leading down to a water manometer was attached. Three of the right-angle turns following the connection to the flue nipple were made by sweeps having a radius of approximately ten inches. The object in providing these was to reduce friction as much as possible.

The carpenter work on the case and the pipe fitting having been completed, the Ados $CO_2$ apparatus was placed in position as shown by the sketch of the installation. The jacket of the motor

was filled with water and a film of oil was spread over the top to prevent rapid evaporation, since the temperature in the pump room is high at all times. Dynamo oil was used to seal the gas pumps while the valves were filled with heavy, commercial glycerine. This glycerine is depended upon to absorb the soot and water vapor carried by the flue gas since the pipe line contains no filter. To provide the sealing liquid for the moving bottle and for the bell under the pen arm, one part of glycerine was mixed with two parts of water. This mixture was poured into the vessels until the liquid worked up to the proper levels. The vessel A, was filled to the mark indicated with a solution of caustic potash of 375 parts by weight of the potash, to 875 parts by weight of the water, thus producing a specific gravity of 1.27. Connections were made by means of rubber tubing to the draft and flue gas pipes and to the recording cabinet. The apparatus was then ready to operate.

## Operation and Test.

Some difficulty was encountered in operating the machine as will be explained. It was found upon starting the apparatus, that the glycerine solution from the moving bottle did not act up to the mark indicated, and therefore 100 cubic centimeters of gas were not forced into the caustic potash solution; also the stroke of the pen was too great for the height of the card.

The first difficulty was overcome by shortening the wire holding the counterweight, thus increasing the height to which the level of the moving liquid rose. This level was brought to the mark when the moving bottle was at the end of its upward

stroke.

The second difficulty was overcome by changing the length of the two vertical rods below the lever arm, so that when the apparatus was analyzing air only, the pen passed from the bottom to the top of the chart showing no $CO_2$. In order to facilitate this adjustment, one-half inch in length was added to the pen arm while the bell arm was shortened one-quarter inch.

The method of test in general, consisted of running the Ados Recorder at various speeds and checking the indications of the chart by means of the Orsat apparatus. The effect of different speeds upon the indications of the chart would thus be determined.

In pursuance of the above method, a chart was placed upon the drum of the Recorder and the motor was operated at full speed, air alone being admitted to the pumps. When the liquids were acting to their proper levels, the pen was adjusted to make a stroke from the 20% line to the 0% line and back again. The pumps were then connected to the pipe carrying the flue gas and, after three or four strokes, required to expel the air, the chart showed the results of the analyses.

Before attempting to use the Orsat apparatus for checking the indications of the chart on the drum of the Recorder, fresh caustic potash solution of a specific gravity of 1.27, the same as that in the recording cabinet, was placed in one of the pipettes of the instrument to absorb the $CO_2$. In order to obtain a sample of gas for analysis, a water siphon composed of two large bottles fitted with rubber corks and the necessary tubing, both glass and rubber, was used to draw the gas from the vertical pipe mentioned previously as being tapped into the flue gas line close

to the nipple at boiler number one. Before drawing a sample for analysis, the gas already in the pipe was extracted and wasted. Then when a sample was drawn for analysis in the Orsat apparatus, it was noted which cylinder of the pumps was drawing in a like charge of gas and the per cent of $CO_2$ in the gas from this cylinder, as shown by the chart, was compared with that obtained from the Orsat. The flue gas passed into the pipette of the Orsat apparatus was allowed to remain in intimate contact with the caustic potash solution for a sufficient length of time completely to remove all of the $CO_2$.

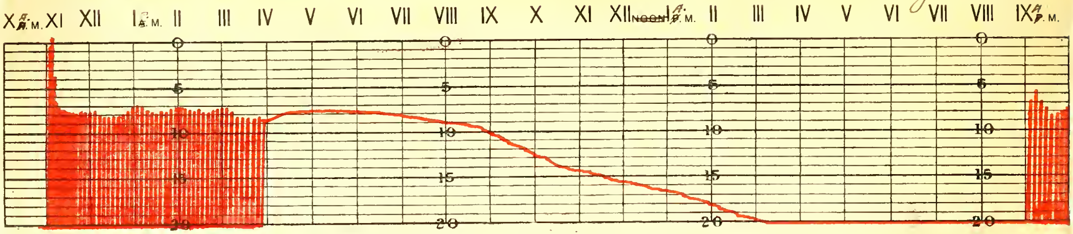
The Recorder was operated for an hour or two at a speed such that two minutes were required for two strokes of the motor, one up and one down. Analyses were made by means of the Orsat apparatus every fifteen or twenty minutes, and these were compared with the indications of the chart. The draft was then cut down by means of the valve until the time required for two strokes was four, six, eight, etc. minutes, provided the first readings of the chart checked closely with the Orsat results. If this were not the case, the counterweight on the lever arm was shifted toward or away from the pen, thus increasing or decreasing the per cent of $CO_2$ indicated by the chart, until the indications did check closely with the results of the Orsat apparatus. Data was taken for these runs showing time, draft in inches of water, time of rise of motor bell, time of descent of bell, per cent of $CO_2$ indicated by the chart, and the per cent of $CO_2$ shown by the Orsat apparatus. This data is incorporated in the log sheets attached.

## Results.

Chart number one was put upon the drum at 11:00 o'clock A. M., May 22, the pumps drawing in air for regulation of the stroke until 11:20 o'clock A. M., when the flue gas was turned on. At 4:00 o'clock P. M. the counterweight of the motor stuck under the shelf upon which the motor rests, and the air valve was not tripped. Therefore the motor bell failed to come down and the pen descended slowly as the displaced air leaked out from under the brass bell controlling the motion of the pen arm. At 9:00 o'clock A. M., May 23, the counterweight was released and the apparatus operated until 10:00 o'clock A. M., when the chart was removed. No checking was attempted with this chart by means of the Orsat apparatus.

Chart number two was placed upon the drum at 10:00 o'clock A. M., May 23, and was regulated on air until 10:20 o'clock A. M., when the flue gas was admitted to the pumps. The boiler was cut out from 11:45 P. M. to 5:00 o'clock A. M.; therefore there was not sufficient draft to operate the motor between 3:45 and 4:30 o'clock A. M. In checking the indications of the chart, the apparatus was operated at three different speeds but showed an error of 0 to .7 of one per cent, the fastest speed giving the best results. See data sheets #1 and #2. At 8:20 A. M., May 24, the speed was cut down to eleven minutes and forty seconds a round trip of the motor and the checking with the Orsat apparatus was continued. At 8:50 A. M. the analyses were so widely different that it was evident that the same sample was not analyzed in both cases. The other analyses showed the record to be reading high and therefore the counterweight was shifted to allow the pen to rise higher.

#1 % $CO_2$ record. Average for 24 hrs. % Date. May 22, 1907.




Boiler No. 1.

Remarks Motor stuck IV P.M. to IX A.M.

#2 % $CO_2$ record. Average for 24 hrs. % Date. May [illegible], 1907.


Boiler No. 1.

Remarks Boiler shut down 11:45 P.M. to 5 A.M. No draft 3:45 to 4:30 A.M. Chart removed 9:20 A.M.

Data Sheet #1.

Observer J. L. Ehretsman May 23, 1907.

| Time | % $CO_2$ Orsat | % $CO_2$ Chart | Draft In. $H_2O$ | Time Up Sec. | Time Down Min. | Sec. |
|---|---|---|---|---|---|---|
| A.M. 10:55 | 6.4 | 7.1 | .375 | 40 | 5 | 18 |
| 11:20 | 6.2 | 7.0 | .375 | 40 | 5 | 18 |
| P.M. 12:42 | 6.0 | 6.6 | .375 | 40 | 5 | 18 |
| 1:00 | 6.6 | 6.8 | .375 | 40 | 5 | 18 |
| 1:12 | 6.4 | 6.8 | .375 | 40 | 5 | 18 |
| 1:25 | 6.8 | 7.0 | .375 | 40 | 5 | 18 |
| 2:10 | 5.6 | 5.9 | .375 | 40 | 1 | 20 |
| 2:30 | 6.0 | 6.0 | .375 | 40 | 1 | 20 |
| 2:40 | 6.0 | 6.0 | .375 | 40 | 1 | 20 |
| 2:52 | 6.4 | 6.7 | .375 | 40 | 1 | 20 |
| 3:30 | 6.7 | 7.0 | .375 | 40 | 3 | 10 |
| 3:40 | 6.8 | 7.0 | .375 | 40 | 3 | 10 |
| 3:55 | 6.7 | 7.0 | .375 | 40 | 3 | 10 |
| 4:05 | 6.4 | 6.6 | .375 | 40 | 3 | 10 |
| 4:23 | 6.5 | 6.8 | .375 | 40 | 3 | 10 |

Chart number three was put on at 10:25 o'clock A. M., May 24, It was regulated on air as usual and flue gas was admitted to the pumps. Beginning at a speed of the motor corresponding to two minutes a round trip, the indications of the chart were checked with the indications of the Orsat apparatus. For the three readings taken at this speed and the two taken at a speed corresponding to two minutes and forty seconds a round trip, the checking varied only one tenth of one per cent, which difference is well within the limits of observation of the readings of either instrument. See data sheet number two. In fact it is doubtful if is wise to estimate the chart closer than one quarter of one per cent.

An inspection of this and other charts will show that there is a variation from a high to a low value of the per cent of $CO_2$, which variation is almost periodic occurring nearly at intervals of one hour. This is caused by the fireman's varying the speed of the stoker engine, which is regulated by changing the setting of the Gardner governor, and by different depths of coal in the hopper which feeds the chain grate.

Chart number four was put upon the drum at 11:30 o'clock A.M., May 27, and the apparatus was regulated on air as usual. Owing to the evaporation of liquids, it was necessary to add water to the motor jacket, and glycerine and water to the vessel containing the small brass bell.

At a speed of the motor corresponding to two minutes per round trip the checking was very good except for the sample taken at 1:05 o'clock P. M. Evidently the same sample could not have been obtained in both cases. At a speed of the motor corresponding

Data Sheet #2.

Observer J. L. Ehrets man.  May 24, 1907.

| Time | % $CO_2$ Orsat | % $CO_2$ Chart | Draft In. $H_2O$ | Time Up | Time Down | |
|---|---|---|---|---|---|---|
| | | | | Sec. | Min. | Sec. |
| A.M. 8:50 | 5.0 | 7.5 | .375 | 40 | 11 | 0 |
| 9:05 | 6.8 | 7.3 | .375 | 40 | 11 | 0 |
| 9.15 | 7.0 | 7.3 | .375 | 40 | 11 | 0 |
| 10:37 | 7.2 | 7.2 | .375 | 40 | 1 | 20 |
| 10:47 | 7.4 | 7.5 | .375 | 40 | 1 | 20 |
| 10:57 | 7.8 | 7.8 | .375 | 40 | 1 | 20 |
| 11:15 | 6.8 | 6.9 | .375 | 40 | 2 | 0 |
| 11:23 | 7.0 | 6.9 | .375 | 40 | 2 | 0 |

Remarks: The first set of readings were made upon chart number two, while the second and third set were made upon chart number three. Chart number three was placed upon the drum at 10:25 o'clock A. M.

Data Sheet #3.

Observer J. L. Ehretsman. May 27, 1907.

| Time | % $CO_2$ Orsat | % $CO_2$ Chart | Draft In. $H_2O$ | Time Up | Time Down | |
|---|---|---|---|---|---|---|
| P.M. | | | | Sec. | Min. | Sec. |
| 1:05 | 2.0 | 4.2 | .375 | 40 | 1 | 20 |
| 1:15 | 3.6 | 3.5 | .375 | 40 | 1 | 20 |
| 1:21 | 3.9 | 4.0 | .375 | 40 | 1 | 20 |
| 1:30 | 3.8 | 3.8 | .375 | 40 | 1 | 20 |
| 2:10 | 6.5 | 6.5 | .375 | 40 | 3 | 40 |
| 2:22 | 5.3 | 5.4 | .375 | 40 | 3 | 0 |
| 2:28 | 6.8 | 7.0 | .375 | 40 | 3 | 0 |

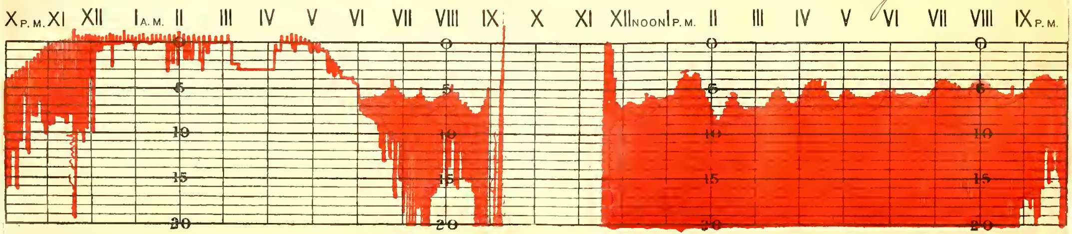
Remarks: Chart number four was put upon the drum at 11:30 o'clock A. M. and the above readings were made from that.

#3 % $CO_2$ record. Average for 24 hrs. % Date. May 24 1907.


Boiler No. 1.

Remarks Boiler shut down 10:45 P.M. [illegible] 4:30 A.M. Machine started on air at 10:25 A.M.
[illegible] 10:70 A.M.

#4 % $CO_2$ record. Average for 24 hrs. % Date May 27 1907.




Boiler No. 1

Remarks Started on air 11:30 A.M. Lever stuck 8:50 A.M. to 8:45 A.M; counterweight not in proper position.

to three minutes and forty seconds, the checking with the Orsat apparatus was excellent. The chart shows that the lever stuck and failed to allow the pen to return to its initial position for each stroke from 8:50 P. M. to 8:45 A. M. This was due no doubt, to insufficient weight on the pen end of the lever.

The boiler was cut out from 11:00 P. M. to 5:00 A. M. The chart was removed at 9:20 A. M. No adequate explanation of the overriding of the pen between 11:00 and 5:00 o'clock is offered.

Chart number five was put on at 9:20 A. M., May 28, and the apparatus was regulated on air. The first set of readings at high speed showed the recorder to read two to six tenths high. See data sheet #4. Therefore the counterweight was shifted to permit the pen to rise higher. The weight was again adjusted after the second set of readings had been taken, and the third set showed good checking. At a speed of the motor corresponding to six minutes and twenty seconds for two trips, the agreement of results was very good.

At 11:30 P. M. the boiler was cut out. It was cut in again at 5:45 A. M. Insufficient draft to run the motor was obtained from 1:45 to 4:00 A. M. The chart was removed at 8:50 A. M.

Chart number six was placed upon the drum at 10:30 A. M., May 29, and was regulated on air. The stroke was very irregular on gas, producing bad results as compared to the Orsat apparatus. Air was again admitted to the pumps and the stroke was again regulated until 2:15 P. M. The Recorder still showed too little $CO_2$ by about one per cent even after shifting the counterweight. See data sheet #5. The caustic potash solution was renewed at 3:55 P.M. after which the absorption seemed to be better, as high as eight

Data Sheet #4.

Observer J. L. Ehretsman May 28, 1907.

| Time | % $CO_2$ Orsat | % $CO_2$ Chart | Draft In. $H_2O$ | Time Up | Time Down | |
|---|---|---|---|---|---|---|
| | | | | Sec. | Min. | Sec. |
| A. M. 10:00 | 6.4 | 6.2 | .375 | 40 | 1 | 20 |
| 10:10 | 6.0 | 6.5 | .375 | 40 | 1 | 20 |
| 10:18 | 5.8 | 6.4 | .375 | 40 | 1 | 20 |
| 10:33 | 5.4 | 5.8 | .375 | 40 | 1 | 20 |
| 11:05 | 7.0 | 7.2 | .375 | 40 | 1 | 20. |
| 11:17 | 5.2 | 5.4 | .375 | 40 | 1 | 20 |
| 11:30 | 6.6 | 6.5 | .375 | 40 | 1 | 20 |
| 11:43 | 6.6 | 6.8 | .375 | 40 | 1 | 20 |
| P.M. 12:03 | 5.2 | 5.2 | .375 | 40 | 1 | 20 |
| 1:08 | 4.4 | 4.4 | .375 | 40 | 5 | 40 |
| 1:21 | 5.2 | 5.0 | .375 | 40 | 5 | 40 |
| 1:37 | 5.6 | 5.5 | .375 | 40 | 5 | 40 |

Remarks: All of the above chart readings were taken from chart number five which was placed upon the drum at 9:20 o'clock A. M.

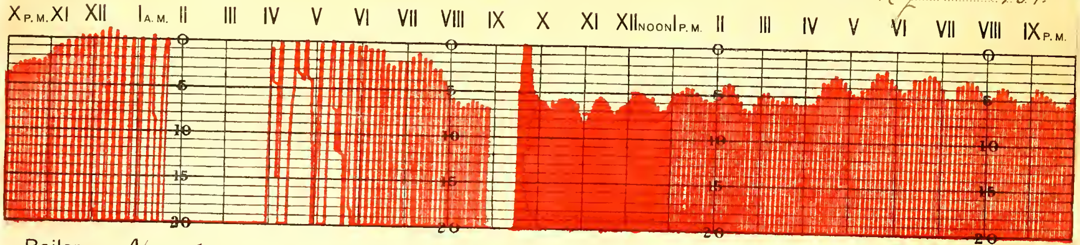
Data Sheet #5.

Observer J. L. Ehretsman. May 29, 1907.

| Time | % $CO_2$ Orsat | % $CO_2$ Chart | Draft In. $H_2O$ | Time Up Sec. | Time Down Min. | Sec. |
|---|---|---|---|---|---|---|
| A.M. 11:05 | 6.0 | 5.5 | .375 | 40 | 3 | 10 |
| 11:20 | 5.6 | 5.2 | .375 | 40 | 3 | 10 |
| P.M. 12:12 | 6.0 | 4.8 | .375 | 40 | 1 | 20 |
| 2:15 | 7.6 | 5.8 | .375 | 40 | 1 | 20 |
| 2:35 | 6.0 | 4.6 | .375 | 40 | 1 | 20 |
| 2:50 | 6.6 | 5.2 | .375 | 40 | 1 | 20 |
| 3:05 | 6.2 | 5.0 | .375 | 40 | 1 | 20 |
| 3:20 | 6.4 | 5.5 | .375 | 40 | 1 | 20 |
| 3:37 | 7.8 | 6.8 | .375 | 40 | 1 | 20 |

Remarks: The above chart readings were taken from number six which was placed upon the drum at 10:30 o'clock A. M. The caustic potash solution was renewed at 3:55 o'clock P. M.

#5 % $CO_2$ record. Average for 24 hrs. % Date. May 28 1907.




Boiler No. 1

Remarks Started on air 9:20 A.M. Boiler shut down 11:30 P.M. to 5:46 A.M. No draft 1:45 A.M. to 4 A.M.

#6 % $CO_2$ record. Average for 24 hrs. % Date. May 29 1907


Boiler No. 1.

Remarks On air at 2:15 then on gas. Caustic potash renewed at 3:55 Boiler cut out 10:15 P.M.

per cent of $CO_2$ being reached.

At 10:30 P.M. the boiler was cut out and there was no draft from 1:30 A.M. to 5:15 A.M. The apparatus was run on air until 8:50 A.M. when the chart was removed.

Chart number seven was placed upon the drum at 9:30 o'clock A.M. and regulated on air until 10:15 A.M., May 31, when gas was admitted to the pumps. No checking was attempted with this chart by means of the Orsat apparatus. The boiler was cut out from 10:45 P. M. until 5:00 A. M. There was not sufficient draft to operate the motor from 2:50 to 3:30 A. M.

The reason for the short stroking shown during the night is not apparent since the stroke was regulated properly when the chart was put on. It may however, have been due to the falling of the level of the liquid in the moving bottle due to evaporation.

Chart number eight was placed upon the drum at 9:10 A.M., June 3, and was regulated on air as usual. Gas was admitted and one or two samples of gas were taken for the Orsat apparatus. The results of the analyses of the Orsat and the Recorder did not agree however, and, since over stroking was suspected, due to increase in level of the liquid in the moving bottle, the stroke was again regulated on air at 1:45 P. M. Better agreement of the analyses resulted.

The boiler was cut out from 11:00 P.M. to 4:45 A.M. and, for a portion of that time there was not sufficient draft to operate the motor. The chart was removed at 8:45 A. M.

Chart number nine was put on at 9:00 A. M., June 4. No checking with the Orsat apparatus was attempted. The short strokingof the pen shown after cutting out the boiler at 10:15 P.M. was due

#7 % $CO_2$ record. Average for 24 hrs. % Date. May 31 1907.


Boiler #1

Remarks Put on gas 10:15 A.M. Boiler cut out 10:45 P.M. to 5:00 A.M. No draft 2:50 to 3:30 A.M.

#8 % $CO_2$ record. Average for 24 hrs. % Date. June 3, 1907.


Boiler No. 1

Remarks Apparatus regulated 9:10-9:30 A.M. and 1:45-2:00 A.M. Boiler cut out 11:00 P.M. to 4:45 A.M.

to failure of the liquid in the moving bottle to act up to its proper level.

The boiler was cut in at 4:45 A.M. From 1:00 to 4:00 A.M. there was not sufficient draft to operate the motor. The chart was removed at 9:35 A.M.

Discussion of Results and of the Conditions Affecting Them.

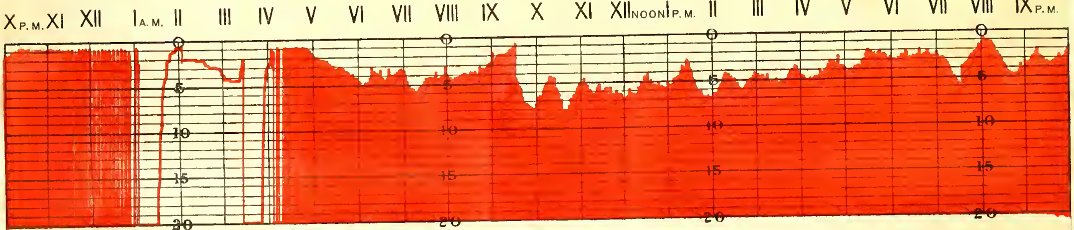
It is a well recognized fact that no apparatus now in use for analyzing flue gas shows the exact amount of $CO_2$ contained in that gas. The Orsat apparatus reveals an error of approximately five per cent in its analyses, and therefore the comparison with the Ados Recorder gives only a relative instead of an absolute value. This is sufficient however, since a record of analyses as correct as those of the Orsat is accurate enough for all purposes.

An inspection of the charts and data sheets shows that although the Ados Recorder can be regulated to indicate for a time the same per cent of $CO_2$ as the Orsat apparatus, the results are not reliable after the lapse of six to twelve hours, owing to variations of the stroke of the pen caused by changes inherent in the apparatus.

The temperature within the case of the apparatus was practically constant during the day since exhaust pipes and a feed water heater are distant only about six feet. The effect of extreme variations of temperature either at the apparatus or in the flue gas, was not determined.

Variations of chimney draft, which of course caused corresponding variations of speed, seemed to have little or no effect upon the results. As an example of this, see data sheet #2, and chart four of May 27. Also see data sheet #3 and chart five of

#9 % $CO_2$ record. Average for 24 hrs. % Date. June 4, 1907.




Boiler No. 1.

Remarks Chart put on at 9:00 A.M. Boiler cut out 10:15 A.M. to 4:45 A.M. June 5 chart laps over June 4 at 9:00 AM

May 28.

Variations of the stroke of the pen seriously affect the results. The reasons for these variations are discussed in the following pages.

Advantages and Disadvantages of the Ados Recorder.

One of the advantages of using an apparatus like the Ados lies in the fact that a continuous record is obtained for twenty-four hours, of the per cent of $CO_2$ in the flue gas. These analyses may be made every two minutes if desired and the results of the analyses are at once apparent to the engineer or furnace operator by an inspection of the chart.

Even though the results indicated by the chart are not absolutely correct, still the engineer or fireman is enabled at a glance to tell when he is getting a maximum and when a minimum per cent of $CO_2$ in the flue gas. Therefore better results in the operation of the furnace might be expected.

One great disadvantage to be found in the use of this apparatus, is the time required for regulating it and for keeping it in condition to produce correct charts. At least one half hour is required to remove the old chart, place the new one on the drum, to regulate the stroke on air, and for the apparatus to begin recording gas analyses. Even after regulating the stroke on air, the indications of the chart cannot be depended upon as being accurate without checking, and checking with the Orsat apparatus requires considerable time. In fact, the Recorder requires almost constant care and attention in order that one may be certain of the correctness of the indications of the chart.

Other things which make it necessary to watch the Recorder carefully are troubles caused by dirt in the valves, sticking,

and evaporation of the liquids. These tend to render the apparatus inoperative and to destroy the accuracy of the chart.

As stated previously, no filter was used in connection with the pipe through which the flue gas was drawn from the boiler. Instead the glycerine in the valves was depended upon to catch any soot carried over by the gas. This glycerine rapidly became filled with dirt and it was found to be advisable to renew this liquid once in forty-eight to seventy-two hours of continuous operation.

Sticking of the motor may be caused by mechanical difficulties such as striking of one of the studs against the top of the valve arm, or insufficient pressure of the stud on the arm to cause it to trip the valve. Troubles of this kind are easily remedied when they occur and can be prevented by proper care.

Another difficulty encountered in the operation of the apparatus is that of the change in the levels to which the solutions act, by virtue of evaporation of water from them. It is necessary to add water to the motor jacket once in seventy-two hours to maintain the level and prevent the bell's sticking at the top of its stroke. Evaporation of water from the moving bottle causes a decrease in the volume and, when the liquid rises in the gas vessel of the recording cabinet, it does not rise to the same height. Therefore 100 cubic centimeters of the flue gas are not driven into the bottle A, and the results are correspondingly inaccurate. The caustic potash solution showed no signs of evaporation in 144 hours but it had absorbed too much $CO_2$ by that time to work properly.

To prevent evaporation of the water in the motor jacket, a film of oil was distributed over the surface. Probably a better way would be to inclose the case tightly and to keep the humidity

within high by causing water to drop into the case. This would also tend to prevent evaporation of the water from the glycerine solution in the moving bottle. The best mixture to use in making up the solution for this bottle is one part of glycerine to one part of water. Such a solution acts quickly enough and, at the same time, does not lose by evaporation to the same extent as the two to one solution. The above mixture is also recommended for sealing the brass bell which actuates the pen arm.

Another important disadvantage is found in the inaccuracy of the charts. Inaccurate records may be produced by any of the causes just discussed but, even if the pen is stroking properly, an inaccurate chart is produced for the reason that the ink, when placed upon the paper by the pen, is caused to spread to a great extent by capillary action of the paper. In checking with the Orsat apparatus, the position of the pen was noted at the top of its stroke thus eliminating any error due to spreading of the ink. If, however, at any time, the per cent of $CO_2$ in the flue gas at any previous time is read from the chart, an error of from one-quarter to three-quarters of one per cent is introduced by the action of the paper on the ink. To reduce this error to a minimum or to eliminate it entirely, it is recommended that a good, glazed paper be used for the charts.

The cost of the Ados Recorder is another disadvantageous feature and prohibits its use in small plants since, in such places, the saving in the coal burned would not be great enough to warrant the installation of an apparatus of this kind. The Recorder represents an investment of three hundred dollars. The expense of maintaining and operating the apparatus is slight, if attendance is

not considered, since only small quantities of very cheap solutions are used. Breakage entails much delay and expense however, since all of the parts of the apparatus are made in England.

To sum up, the advantages to be derived from the use of this apparatus lie in the fact that it is continuous in its operation and furnishes a graphical record of analyses which, if not absolutely correct, shows the relative per cents of $CO_2$ in the flue gas at different times enabling the furnace operator better to control his furnace. The disadvantages of the apparatus are that it requires almost constant care and attention owing to dirt collecting in the valves, sticking of the motor, and evaporation of the liquids; that it furnishes an inaccurate record owing to the spreading of ink on the chart even if the pen is stroking properly; and that it is an expensive apparatus both as to first cost and repairs.

# B I B L I O G R A P H Y


Encyclopaedia Brittanica---------volume 22, page 180.

Fuel Economies------------Maker's pamphlet.

Kent's M. E's. Handbook--------------------page 694.

Scientific American Supplement---Dec. 22, 1906, volume 42.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